SECTION II.—GENERAL METEOROLOGY.

METEOROLOGICAL OBSERVATIONS IN CONNECTION WITH BOTANICAL GEOGRAPHY, AGRICULTURE, AND FORESTRY.

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The title of this paper is really more ambitious than its contents. It is far beyond one ordinary man's power to prepare a comprehensive plan for meteorological observations that would meet the needs of botanists, agriculturists, and foresters, especially if this man happens to be only a forester. I hope, however, that these suggestions, meager as they are, may at least result in a discussion of this important subject.

I wish to make it entirely clear that I have no intention whatever to criticize the records as now collected by our own or any other Weather Bureau. First, present methods of gathering and publishing weather data are a result of international agreement and can not be readily changed to suit the needs of any one particular interest. Second, I am not certain that it is within the function of any weather bureau to work up the meteorological data in the manner in which they are needed by botanists, foresters, and agriculturists; its primary duty is to secure original data which can be computed in any form needed by students of plant life. Third, plant ecologists have never to my knowledge formulated any constructive plan for working up meteorological data that would be acceptable to botanists in general. If the present meteorological data are not exactly in the shape in which they can be most effectively used for interpretation of plant life, it is therefore not so much the fault of the meteorologists as the fault of the botanists themselves.

Some criticize the weather records because they do not show the thermal units of heat and the actual amounts of humidity that plants utilize in their life processes; others, because they do not include measurements of a number of physical factors which affect plant life; while still others consider the distribution and location of many weather stations to be inadequate for a proper interpretation of the distribution of vegetation over the country; and so on. But these questions refer to biology, not to climate. There is no doubt but that meteorological observations generally interpret climate from a purely meteorological point of view and ignore almost entirely the biological side. The fault, however, in my opinion, lies not so much in the kind and character of observations that are being recorded as in the manner of their classification, their grouping and computing. Any broad plan for meteorological observations covering a large country, even when viewed from an entirely biological point of view, must necessarily confine itself to observations of such climatic factors as affect only the fundamental processes of the growth of vegetation in general, without attempting to provide data for the understanding of some specific phases in the development of a plant. The latter must always be a subject of special investigation.

Some of the criticisms directed against the present weather records on the ground that they do not show the exact amounts of heat or moisture utilized by plants do not seem to me well founded. For instance, it is true that plants do not make use of the amount of available heat. Even with an exact knowledge, however, of the absolute quantities of heat and moisture which plants receive in a given locality, still we would not know their absolute climatic requirements. Most of the introduced plants tend to retain in their new home their inherited phenological habits. It is well known that the oak and the beech which, in their original home in the Temperate Zone, normally shed their foliage in October and November, on being transplanted to the island of Madeira continue to shed their foliage in these two months in spite of a climate favoring their growth during the fall. Another striking example is found in our Rocky Mountain and Pacific coast Douglas fir. Douglas fir from the Pacific coast when grown in a continental climate does not withstand frosts, while the Rocky Mountain form of Douglas fir does so no matter where it is planted. For this reason even most accurate measurements of heat and moisture would not be of any material help to us in determining the climatic requirements of plants, because we do not yet know to what extent a given species or variety of plant will utilize the available heat and moisture for its life functions.

With our present knowledge of the requirements of the various species, varieties, and biological races of plants for heat and moisture we can only aim to compare the climate of a given locality with the climate of other localities in which the same plants are growing thriftily. For this reason what we need at present are not meteorological data of absolute accuracy, but rather data that will permit of an accurate comparison between the climatic features that are essential to plant life in different localities. The combination of purely meteorological and biological viewpoints in classifying and computing meteorological observations for purposes of botany seem to me absolutely essential. With our present meteorological observations secured at the weather stations, but with a different method of grouping them, it is possible to secure results which would be of value to students of plant life. I shall attempt to indicate here the manner in which the original meteorological observations should be classified and computed in order to make them of value to biologists, and shall cover briefly temperature of the air, precipitation both in the form of rain and snow, relative humidity of the air, wind movement, and barometric pressure.

Temperature of the air.

Mean annual temperature.—It is common to characterize a given locality by its mean annual temperature. This temperature is, of course, important for the general climatic orientation, but has no direct bearing upon plant life.

Mean seasonal temperature.—Another common way of grouping the temperature data is by the four astronomical seasons, spring, summer, autumn, and winter. This method by seasons is void of any significance for the proper understanding of plant life. It is, of course, ridiculous, for instance, to consider March as a spring month in the State of Maine when the entire vegetation is still in its period of rest, the ground covered with a deep layer of snow, and the temperature below freezing.

Periods of growth and rest.

Properly to understand plant life it is essential to group temperature data by periods of growth and rest. During each of these two periods plants react to temperature of the air in altogether different ways. Aside from the herbaceous vegetation, which during the period of rest is entirely hidden in the ground, trees require different amounts of heat during the period of rest and period of growth. Thus the Siberian fir (*Abies sibirica*), which during its period of rest withstands with impunity the lowest temperatures ever recorded anywhere on the earth's surface, in the spring has its terminal shoots killed at a temperature of 28.5° F. For this reason Siberian fir forms vast forests near the thermal pole, but is killed by frost in the Valley of the Rhine. It is evident that mean annual temperatures, or mean seasonal temperatures, could not throw any light whatever upon phenomena of this character. At some experiment stations, here and abroad, the grouping of meteorological data by periods of growth is in use, but chiefly with reference to some definite phases of development of several of the important agricultural plants. Painstaking computations of such observations is time consuming; it would be a difficult task to attempt to secure them for most plants. Even if it were possible to obtain such observations they would not provide a common, reliable basis for comparing the climatic features essential to plant life in different localities. Thus, the observations upon the temperature data of any given locality should be computed not merely by the period of rest and growth of one or several cultivated plants, but by the general periods of rest and growth of the native vegetation of the locality. In each locality it is possible to determine some climatic features which are especially characteristic and important for the entire natural vegetation of the region. These fundamental characteristics of a given local climate are also of importance for the cultivated plants within the region.

If we exclude the climate of the Arctic region, which, within the United States, is found only at high elevations within the Alpine zone of the Rocky Mountains, Cascades, and Sierras, and in the Appalachian range in the Northeast, and excluding also the subtropical region which is confined to Florida, southern California, Arizona, New Mexico, and areas in close proximity to the Gulf, then we find that most of this country lies within the temperate region of the globe. The temperature records of this temperate region of the United States not reduced to sea level, should be separately computed on the basis of the local normal monthly mean for the cold period, or period of rest, and the moderate period, or period of growth, and in some localities also for a third period, the hot period. The cold period should include, according to Köppen, all months having a normal mean temperature of 48° F. or less; this embraces the period of more or less complete rest of the majority of plants of the Temperate Zone. In the period of growth, or moderate period, should be included all months having a normal monthly temperature of from 49° to 72° F. This last period in the Temperate Zone is that of most active growth and of the ripening of fruits of all kinds. The third, or hot period, in temperate latitudes should embrace months with a normal average temperature of more than 72° F. Where there is a lack of precipitation or irrigation, this means the period of summer rest; when there is a sufficient amount of precipitation, the period of ripening of southern fruits; and when there is an abundance of moisture, the period of subtropical growth.

The division into periods of growth and rest in the Arctic and subtropical regions must probably be made on a somewhat different basis than the division in the temperate region. The cold period in the Arctic region continues practically the entire year, and whatever growth takes place must occur at temperatures at which most of the vegetation in the temperate region is still in a dormant stage. The Arctic and true Alpine plants require for their development a very small amount of heat, but demand invariably a long period of rest, the lack of which is more harmful to them than anything else. In the subtropical region the plants as a rule are entirely indifferent to surplus of summer heat, but require during the vegetative period a certain amount of moisture, and during the cold period do not withstand any great fall of temperature.

The duration of the three different periods—cold, moderate, and hot—must be determined for each locality or region on the basis of normal mean monthly temperatures, not reduced to sea level. The climate of the United States in this respect is well enough known to make it entirely possible to prepare a map in which the localities that are of agricultural importance and having the same duration of these different periods could be grouped. The preparation of such a map for our mountain regions is yet hardly possible, at least with any degree of accuracy, although some attempt may be made even on the basis of our still inadequate information. The map (fig. 1) here presented has been prepared in accordance with the foregoing plan, and represents the first attempt of its kind. The periods of growth and rest shown in the map are based on the mean monthly temperatures for 685 stations given in Bulletin Q of the U. S. Weather Bureau, "Climatology of the United States," by A. J. Henry.

Thus the monthly mean temperatures, if grouped by periods of actual plant activities, are of importance not only to meteorologists, but also to botanists. Their reduction, however, to sea level, which is practiced by meteorologists in their maps for certain studies, is extremely inadvisable for purposes of studying plant life.

In addition to the monthly mean temperatures, the average temperatures by periods of ten days (decades) are also desirable. In any locality such averages are useful to botanists only during certain months; in temperate regions chiefly at the end and at the beginning of the growth period; and in the more southern latitudes during the entire cold period. Since, however, in different localities the 10-day periods are important for different months of the year, an attempt should be made to give the means for all 36 decades of the year. The pentads of Dove are appropriate for more intensive studies.

Aside from the monthly mean temperatures and mean temperatures for periods of 10 days, it is also of importance to have information about the mean temperatures for the period the ground is covered with snow and for the period when the ground is bare. The protective value of snow against injury from low temperatures to herbaceous and low arborescent vegetation, especially winter crops, is well known. The depth of the snow cover is often the determining factor in the distribution of some of our trees. A species when planted north of its natural range, may grow at first very thriftily and withstand winters without injury as long as it is covered with snow. As soon, however, as its terminal shoots begin to rise above the snow line they are invariably killed. Those which sprout prolifically from the stump renew themselves every year by means of root suckers, and often produce flowers, thus becoming low shrubs.

Closely associated with the effect of temperature upon plant growth is the effect of the wind. If there were no winds and air currents, every locality would have its own climate. Winds, however, depending upon the direction from which they come, give the locality, as it were, practically a new climate. Biologically it is very important to know the characteristic features of the climates that are brought to a given locality by winds from outside. For this purpose it is not enough to know only the direction and the velocity of the prevailing winds, but also their temperature and humidity. Thus it is essential, aside from general monthly mean temperatures, to compute also the mean temperature for each period during which certain winds prevail. It is not necessary to compute this mean temperature for each wind but only for the main prevailing winds, since, in regard to their effect upon vegetation, winds from several directions may be grouped together, such as southerly winds, easterly, etc.

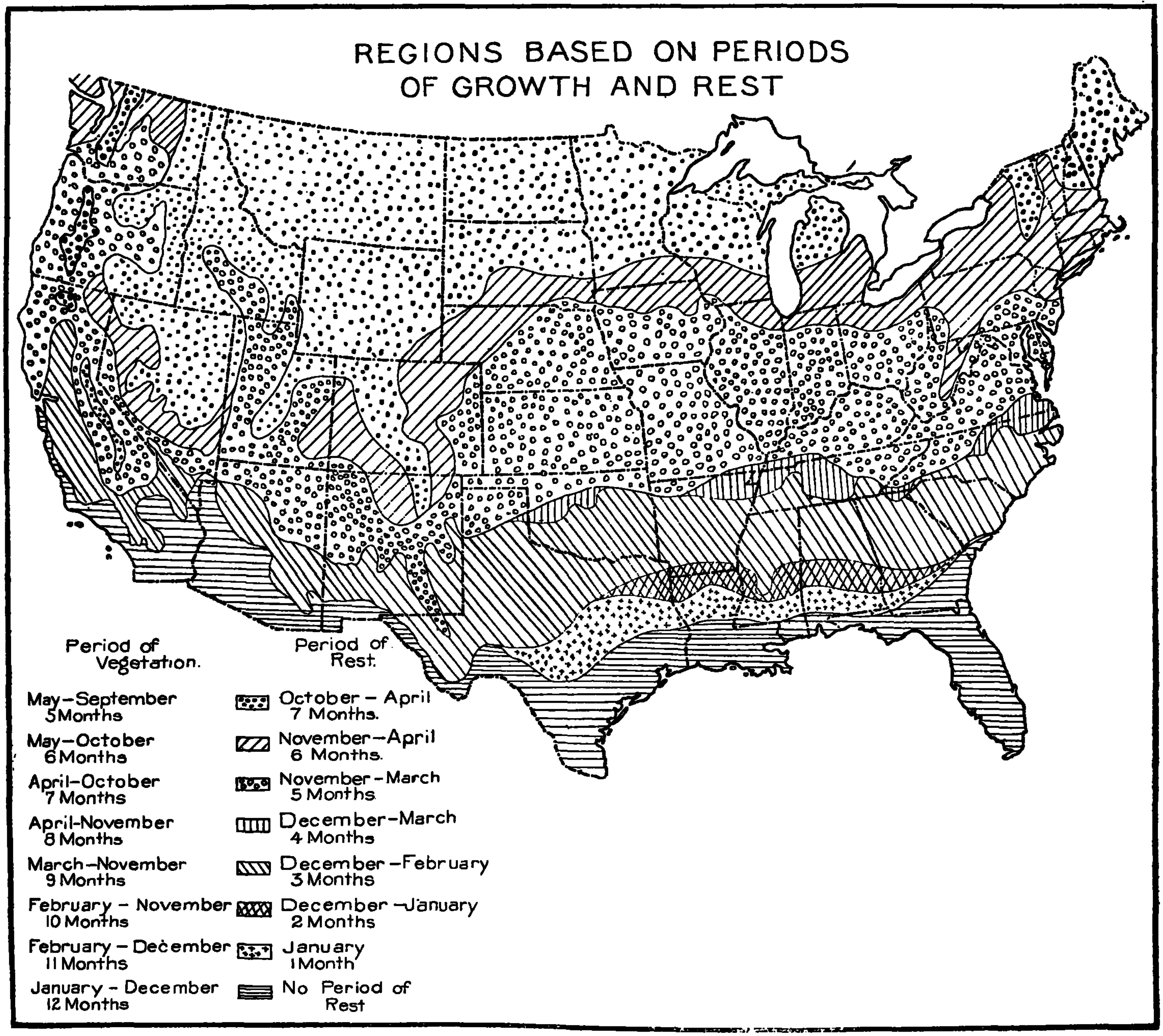

Fig. 1. Vegetal regions of the United States, based on periods of growth and rest deduced from the mean monthly temperatures for 685 stations as given in "Climatology of the United States," by Prof. A. J. Henry, Washington, 1906, Weather Bureau bulletin "Q."

TABLE 1.—*Temperature of the air by periods of rest and growth.*[1]

Month.	Average temperature.	For days with no snow on ground.	For days with snow.	For days with easterly winds.	For days with westerly winds.	For the first 10 days.	For the second 10 days.	For the third 10 days.
Period of rest.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.
November	34.5	40.6	30.0	34.7	34.0	39.7	34.5	29.5
December	31.8	34.0	31.6	32.4	28.6	39.7	26.4	29.5
January	28.0	....	28.0	28.2	27.9	31.8	31.3	21.9
February	26.4	....	26.4	25.9	26.4	30.7	24.1	24.8
March	30.4	....	30.4	29.1	30.6	30.2	28.8	32.0
April	47.3	48.4	46.8	49.6	42.6	48.2	48.6	45.5
Average for the rest-period	33.1	39.0	31.5	34.5	30.9	....	....	....
Period of growth.								
May	54.3	54.3	....	57.4	52.2	52.9	54.0	55.8
June	61.2	61.2	....	62.6	60.4	58.6	60.8	64.0
July	64.4	64.4	....	69.3	60.3	60.1	66.2	66.7
August	64.0	64.0	....	67.6	60.4	62.6	64.4	64.9
September	54.9	54.9	....	58.8	51.1	54.1	61.9	48.7
October	48.6	48.6	....	49.5	47.7	51.3	50.2	44.6
Average for the growth-period	57.9	57.9	....	60.4	....	....	....	....
Average for year	45.5	56.3	31.5	....	....	....	....	....

[1] These records, while they were actually made, are given here not as a characteristic of the region in which they were collected, but merely for the sake of illustrating the method of arranging weather data. This holds true for all the other tables included in the statement.

Absolute daily maximum and minimum temperatures.—The absolute maximum and minimum temperatures of the air should be computed separately for days with no snow on the ground and again for days with a snow cover, since the effect of minimum and maximum temperatures upon plants is very different when the ground is bare and when the ground is covered with snow. Maximum temperatures while the snow is still on the ground are too early and undesirable, because they may force the plant to vegetative activity before the real warm weather has come.

Mean daily maxima and minima.—Since for the plants the occurrence and duration of the maximum and minimum temperatures are of more importance than the brief absolute maximum and minimum temperatures, it is desirable to compute also the mean of the daily maxima and minima for the month and also the maxima and minima of the daily means. The minimum of the daily means should be shown separately for days with snow on the ground and for days without snow.

TABLE 2.—*Temperature of the air by periods of rest and growth.*

Month.	Absolute maximum.		Mean of daily daily maxima.	Maximum of daily means.	Absolute minimum.		Mean of daily minima.	Minimum of daily means.	
	For days with no snow.	For days with snow.			For days with no snow.	For days with snow.		With no snow.	With snow.
Period of rest.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.
November	64.2	42.3	39.6	53.4	33.8	14.0	30.2	37.4	21.4
December	55.4	55.4	35.8	46.8	30.9	14.0	27.7	34.0	18.1
January	....	48.2	31.5	41.4	....	11.3	24.6	......	18.5
February	....	44.8	31.3	44.2	....	12.6	22.3	......	18.5
March	....	58.5	35.6	47.7	....	16.7	25.5	......	23.9
April	69.4	68.5	56.5	57.9	32.0	31.1	39.4	39.0	33.1
Average for the rest-period	69.4	68.5	38.3	57.9	30.9	11.3	28.2	34.0	18.1
Period of growth.									
May	74.1	....	62.4	63.9	39.2	....	45.5	45.9	......
June	79.7	....	69.1	68.4	48.7	....	53.1	53.1	......
July	82.8	....	72.5	71.8	50.0	....	57.7	52.9	......
August	80.6	....	72.0	71.4	44.6	....	57.4	53.2	......
September	80.8	....	61.9	67.8	39.2	....	49.3	46.0	......
October	68.9	....	56.3	56.5	32.0	....	41.9	40.6	......
Average for the growth-period	82.8	....	65.7	71.8	32.0	....	50.9	40.6	......
Average for year	82.8	68.5	52.0	71.8	30.9	11.3	39.6	34.0	18.1

Range of temperature.—For plant life the range of the temperature of the air during 24 hours and during more prolonged periods is of great importance. The effect of temperature fluctuation upon plants is well known. Thus a uniformly severe winter will have an injurious effect upon plants adapted to a given climate only when the preceding summer was short or not sufficiently warm or too humid, and the shoots have not had time to ripen. The most injurious winters are not the severest winters, but winters which are characterized by the least stability of temperature, by rapid changes from thaws to low temperatures. The effect of fluctuations of temperature has been proven by Heppert's laboratory experiments. Thus *Poa annua*, *Senecio vulgaris*, *Capsella bursa pastoris*, and others withstood with impunity long snowless freezes with temperature as low as 14° F. and some even as low as 5° F. After several brief thaws, however, they all perished at a temperature of 24.8° F. The expression "absolute monthly range" may serve only for general orientation, and has no direct bearing upon plant life, since sufficient time may intervene between the occurrence of the maximum and minimum to permit of a gradual change in temperature. For plant life the mean daily range, and the maximum and minimum of the individual daily ranges, therefore, are of greater moment than the absolute monthly range. The mean monthly ranges are also of importance. The mean annual range is more important than the mean periodic range. Particularly instructive is a comparison of the general mean annual range with the mean annual range of temperatures computed separately for winds of different directions.

TABLE 3.—*Temperature of the air by periods of rest and growth.*

Month.	Absolute monthly range.	Mean daily range.	Maximum of the mean daily range.	Minimum of the mean daily range.	Mean monthly range.		
					General.	With easterly winds.	With westerly winds.
Period of rest.	°F.	°F.	°F.	°F.	°F.	°F.	°F.
November	50.2	9.4	27.4	1.4	....	....	....
December	41.4	8.1	20.2	0.9	....	....	....
January	36.9	6.9	19.8	1.8	....	....	....
February	32.2	9.0	22.1	2.3	....	....	....
March	41.8	10.1	23.8	4.0	....	....	....
April	38.3	17.1	29.7	2.0	....	....	....
Range for the rest-period	58.1	10.1	29.7	0.9	20.9	23.7	16.2
Period of growth.							
May	34.9	16.9	27.9	3.2	....	....	....
June	31.0	16.0	24.8	3.2	....	....	....
July	32.8	14.8	26.1	3.6	....	....	....
August	36.0	14.6	25.2	2.7	....	....	....
September	41.6	12.6	25.4	2.5	....	....	....
October	36.9	14.4	23.2	5.2	....	....	....
Range for the growth-period	50.8	14.8	27.9	2.5	15.8	19.8	12.7
Range for the year	77.5	12.4	29.7	0.9	38.0	43.4	34.0

The method suggested here of grouping the temperature of the air will not show the actual amount of heat required for the development of the vegetation in a given locality. Its purpose is merely to furnish material for a more thorough comparison of climates from a biological and meteorological standpoint.

In order to determine the extent to which different plants actually utilize the heat, it is necessary to resort to another method. A number of attempts have been made to secure this information by computing temperature and other meteorological records for the period of growth of a few of the more important agricultural crops.

At first glance such a procedure seems very expedient, but it is doubtful if it can yield practical results. No matter whether an attempt is made to compute the average temperature for a given phase of plant development, or whether the positive temperatures are summed up for a period in the same way in which Bussengo and De Candolle have done it, the underlying idea is the same, namely, that the effect produced by heat upon plants is proportionate to the amount received during the period. In reality there is no such direct relation. On the contrary, for each phase of plant development there exists a definite optimum of temperature, moisture, and light at which the development goes on with the greatest vigor. When the temperature (or moisture, or light) deviates in one direction or the other from this optimum, the development slows down, and when temperature falls below a certain minimum or rises above a certain maximum it stops entirely. The warmer the climate, the more frequently the temperature exceeds the optimum at which the plant develops best and the more often the plant will receive a useless and sometimes harmful surplus of heat. Yet by summing up temperatures or by computing the average temperature for the period, this useless or often harmful excess of heat invariably increases the summation or the average temperature. For this reason, the farther south the greater must be the sum of useful temperature required by the same species to go through a given phase in its development. This clearly shows, it seems to me, that neither the summation of positive temperatures nor the average temperatures for any period can indicate the actual requirements of plants for heat; and most botanists since the time of Grisenbach have given up summation of temperatures.

Bussengo and De Candolle probably would not have suggested this method of summation if they had known about the existence of optimum temperatures for the development of each plant, as determined later by Sachs. There are also some other indications which confirm the fact that plants do not react to heat as simple engines. Thus, for instance, the dormant roots of the lily of the valley, or the dormant branches of cherry were found, when starting growth next spring at the same temperature, to require less time for their development the later their growth had been interrupted in the autum, notwithstanding the fact that in these dormant organs before the interruption of their growth no changes had taken place which could be detected macroscopically or microscopically. Furthermore, not only different species and varieties, but even different biological races of the same variety which morphologically do not differ one from another, require for their development very different amounts of heat. In such cases it would be necessary to compute separately the average temperatures for various periods of development, to sum up the temperatures not only for each species, but even for each of its races, which is a practical impossibility. All this tends to show how unreliable and of how little practical value to the biologist is the method of computing average temperatures, or the summing up of temperatures, for different species of plants separately.

Groups of days with a definite temperature.

The relation of plants to heat is expressed not in the absolute amount of heat required by them, but in a certain combination of time and heat. At its optimum of temperature each plant requires a definite number of days in order to complete a given phase of its development. Any deviation from the optimum in one or another direction will lengthen this period.

Gardeners have learned, in an empirical way, how to manipulate temperatures in hothouses for forcing plants to complete a certain phase of development within a given time. They do not resort to summation of temperatures, but distinguish groups of days with a given range of temperature. Each group of days may embrace temperatures of five consecutive degrees. Fluctuation of temperature within these five degrees is of little consequence. They watch carefully, however, to see that the temperatures during a definite number of days do not fall to the level of the temperature of the group of days preceding it, or rise to the temperature of the group of days that is to follow it. Instead of summation of temperatures, this method seems to me preferable. Groups of days with definite temperatures can be readily computed separately for individual species; also, the entire year may be divided into such groups, as shown in Table 4.

The division of the entire year into groups of days with different temperatures is not a new idea. Many botanists have adopted such a division. Thus, following the scheme suggested for climatology by the meteorologist Köppen, some botanists distinguish: *freezing days* with average temperatures of 32° F. or less, *cold days* with average temperatures up to 50°, *moderate days* with average temperatures up to 68°, *hot days* with average temperatures above 68°, and *hot days with moderate nights* when the minimum temperature is about 50°. Such grouping, however, is too large and schematic. The method used by the gardeners seems to me more practical, and with modifications can be adapted to meet such conditions as exist outside of a greenhouse.

The following simpler classification is here suggested:

1. *Freezing days,* with a daily average of 32° F. or less. These are further subdivided into:

(*a*) Freezing days without thawing.

(*b*) Freezing days with thawing.

2. *Cold days,* with an average daily temperature ranging from 32° to 40° F. This group should be further divided into:

(*a*) Days with frost.

(*b*) Days without frost.

3. *Cool days,* with an average daily temperature from 40.1° to 50° F. This group should be divided into:

(*a*) Days with frost.

(*b*) Days without frost.

Cool days with frost are more dangerous than cold days with frost and occur in localities where the mean daily range of temperature is great.

Days with frost are thus divided into three groups: (1) Freezing days with and without thawing, (2) Cold days with and without frost, (3) Cool days with frost. During the cool days of the spring plants prepare for the period of vegetation, when the germination of seed takes place and the buds of the hardier species open.

4. *Moderate days* with an average daily temperature from 50° to 59° F. These are days of moderate growth. For the four groups of days so far established (freezing days, cold days, cool days, and moderate days) it is desirable to note the temperature separately for the days the ground is covered with snow and for days without any snow cover.

5. *Warm days* with an average daily temperature from 59° to 72°. These are the days of most vigorous growth and the ripening of fruits in the temperate altitudes and latitudes. For most of the plants of the Temperate Zone this is the most important group of days.

6. *Hot days* with an average daily temperature above 72°. In localities where hot days occur comparatively often, especially when there is a distinct hot period, the hot days must be further subdivided into three groups, not so much, however, on the basis of temperature as on the basis of their humidity:

(*a*) Dry hot days, which act depressingly upon vegetation.

(*b*) Moderately humid hot days, which expedite the ripening of southern fruits.

(*c*) Humid hot days, which produce a tropical growth of plants of the humid subtropical region.

The total sum of days of all six groups (freezing, cold, cool, moderate, warm, and hot) must make 365 or 366.

TABLE 4.—*Days having specific air temperatures, by periods of rest and growth.*

Month.	Number of freezing days.				Number of cold days.				Number of cool days.				Number of moderate days.		Warm days.	Hot days.	Hot days with moderate nights.
	Without thaw.		With thaw.		With frost.		Without frost.		With frost.		Without frost.						
	With snow on the ground.	Without snow.	With snow on the ground.	Without snow.	With snow on the ground.	Without snow.	With snow on the ground.	Without snow.	With snow on the ground.	Without snow.	With snow on the ground.	Without snow.	With snow on the ground.	Without snow.			
Period of rest.																	
November	1		2	1	1	1		8				16					
December	4	3		4	4	11	2	3									
January	28		3														
February	4		2		10				3		4						
March	2		6		12		9				2						
April	2		1		5	1	4	2	1	1	1	10		2			
For rest-period	41	3	14	5	32	13	15	13	4	1	7	26		2			
Period of growth.																	
May								2				12		17			
June												2		15	13		21
July														2	29		31
August														7	23	1	31
September												4		11	15		23
October												21		7	3		4
For growth-period								2				39		59	83	1	110
For year	41	3	14	5	32	13	15	15	4	1	7	65		61	83	1	110

The temperature of the soil.

The records of the temperature of the air are characteristic of the environment that surrounds the superterranean part of the plant. The other parts of the plant (the roots) develop in the ground under different temperature conditions. Observations, therefore, on the temperature of the soil are absolutely essential for the proper understanding of plant life. This phase of observation is specially appropriate to agricultural and forest experiment stations.

Topographic conditions affect the temperature of the soil to a more marked degree than they do the temperature of the air. Moreover, the temperature of the lower layers of the air is regulated by the temperature of the soil more than by the direct rays of the sun. The topography of the locality, therefore, must always be taken into consideration in installing soil thermometers. It would be advisable to install a complete set (at a depth of 1½, 12, and 24 inches) near the station itself and in addition, for comparison, two or three incomplete sets (at a depth of 1½ inches and 24 inches) under different topographical conditions.[1] Since the temperature of the soil depends to a large extent upon its physical structure, it is essential, in order to obtain comparable results, to take the physical qualities into account. Therefore, in localities where the physical quality varies within short distances, it is essential to have an additional set of thermometers to bring out the effect of this difference. It may be also advisable to have a set of minimum and maximum thermometers located horizontally on the surface of the soil, although it is hard to determine just what such thermometers do indicate—the temperature of the upper layer of the soil or of the lower layer of the air.

The effect of the temperature of the soil upon the development of plants is unquestionable. The period of rest of the roots is, however, less marked than that of the superterranean parts and in many of the more southerly altitudes is entirely absent. The period of rest for the roots is less stable than the period of rest for the superterranean parts and therefore is more easily affected by artificial means. For this reason, the grouping of temperature records of the soil on the basis of cold, moderate, and hot periods determined on the basis of the average monthly temperature of the air, is not entirely suitable. The lack of observations and investigations along this line, however, does not yet permit of suggesting any other grouping at present; and it may be just as well, at least for the present, to classify the records of temperature of the soil by the periods adopted for plants in general. It may be mentioned here that roots stand sudden fluctuations of temperature even to a less degree than the superterranean parts of plants.

OTHER METEOROLOGICAL DATA.

I have dwelt at length upon temperature because I believe that the system of observations I have outlined in its case should be followed in computing all other meteorological data. The discussion of these latter, therefore, will be brief.

Humidity of the air.

In localities with a dry climate, especially where there is a distinct hot period, observations upon the humidity of the air are essential. While the absolute humidity is

[1] Probably in some instances measurements of soil temperature at a larger number of depths may be desirable. It is believed, however, that for all purposes three depths should be sufficient. Intermediate depths can be computed very accurately by interpolation with curves on which the three points are established.

of no direct consequence to plants, its importance being purely meteorological, the relative humidity affects them directly, since it so largely determines the amount of transpiration. The monthly mean relative humidity and its minimum, and particularly the average relative humidity with its minimum during periods of different wind direction, are things important to know. In localities with a humid climate and without a distinct hot period, where fogs are frequent, observations upon the latter should, of course, give all the information as to humidity of the air necessary for the purposes of botanical geography.[2]

Precipitation.

The important part which precipitation, especially total precipitation, plays in plant life, needs no discussion. The maximum precipitation for any day during the month and the number of days of precipitation are also important. Since among the latter, however, are included days with only traces of precipitation, the resulting data does not give an idea of the intensity of the precipitation or its frequency. For this reason it will be well to compute the number of days with considerable precipitation in per cent of the total number of days of observation in general, as well as specifically, for winds of different direction.

Snow cover.

Snow cover, of course, also has an important effect upon plant activity. Both the number of days with snow on the ground and the depth of the cover should be recorded. Since the depth of the snow varies with the topography, its depth should be measured at different places. In the valley the snow stakes should be placed, if practical, in an open field and in a wood lot; in the mountains on a level place and on two moderate slopes of the prevailing directions. For each month the average depth of the snow cover should represent only those days when snow was actually on the ground. In order to determine the effect of local topographic conditions, it would be well to note the averages separately for each snow stake. Data on the maximum and minimum of snow cover for each month are also essential, and it is very useful to have the depth of the snow separately for every 10 days (decade). Such detailed information concerning the snow cover is especially instructive at the time of its appearance and disappearance. Since it comes and goes in different years and in different localities at different times, however, this average depth should be given for all 36 decades.

Soil moisture.

In dry regions it is necessary for purposes of botanical geography to have a more detailed knowledge of the humidity of the soil than would ordinarily be indicated by the amount of rainfall and snowfall. In such places periodic and systematic determinations of soil humidity giving due consideration to local topographic and soil conditions are important. Unfortunately, such determinations are not only time consuming, but require a great deal of judgment in the selection of soil samples. The amount of moisture in the soil depends upon the latter's physical properties, its method of cultivation, and so on, and can not be determined accurately at the ordinary weather stations. Therefore it would be of great advantage to students of plant life if such determinations could be made at agricultural and forest experiment stations.[3]

Sunshine.

Light is another important factor in the development of plants. The amount available for plants in a given locality depends upon cloudiness and geographic latitude. For this reason, the average monthly cloudiness, the average cloudiness for winds of different directions, and the number of clear, semicloudy, and cloudy days should be computed. Some simple sunshine record, especially for winds of different directions, is also necessary. The occurrence of days with sunshine should be given in per cent of the total number of observations.

Barometric pressure.

Air pressure has no direct bearing upon plant life, except that its observation often makes it possible to forecast changes of importance to agriculture.

CONCLUSION.

In conclusion, I wish to reiterate what I said at the beginning, namely, that, with the exception of the records of soil humidity and soil temperature, the system of meteorological observations I have outlined can be carried out with the data which are regularly obtained by our weather stations. The change from present practice to the system I have described will entail, therefore, merely a different use of present data rather than a radical change in the plan of collection. The aid to botanical geography which such a change would give would far more than compensate, I think, for any inconvenience or added effort that it might bring about.

TASKS AND PROBLEMS FOR METEOROLOGICAL EXPLORATIONS IN THE ANTARCTIC.

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No other region on the earth has witnessed during the past decade, such advances in our knowledge of its meteorological conditions as has that within the higher southern latitudes. As Hann was closing the second edition of his Handbook of Climatology in 1897 he was practically limited in material for the climate of the Antarctic Zone, to that collected in its seas 50 to 60 years previously by Sir James Ross. There was no

[2] The adoption by all weather stations and observers of a standard evaporometer would, in a large measure, solve the question of humidity and wind-movement records and would furnish data directly usable by the plant bi ologists.

[3] Here again the adoption of a standard apparatus seems the only means of obtaining desirable data for large areas and for different regions. The great difference in soils in different localities and the great difficulty in any one locality of obtaining consecutive samples of soil which are physically alike, makes it necessary that any apparatus designed for consistent soil-moisture determinations shall involve the plan of always measuring the same body of soil. The electrical resistance apparatus is good in this respect, but, unfortunately, is not always reliable from a mechanical standpoint. A comparatively simple piece of equipment has been suggested by C. G. Bates of the Fremont Forest experiment station. This is a porous cup which would contain the sample of soil whose moisture was to be determined periodically. This porous cup would fit closely inside a second similar cup, which would, in turn, be located at the bottom of a brass tube at any desired depth below the surface of the ground. To the soil cup would be attached a cord or rod which would extend up through the brass tube. At the top of the tube would be a firmly built platform, on which could be placed a sufficiently delicate balance for weighing the soil cup. When weighing was desired the cup would be raised sufficiently to clear the exterior cup attached to the beam of the balance and then replaced. The contents of the cup might be a sample of the local soil, a standard sand or soil of certain physical and mechanical properties, or a standard salt with a slight avidity for water. Under either plan the moisture of the contents (by absorption or expulsion through the porous walls) would always bear a certain relation to the moisture of the surrounding soil.